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CHEMICAL AND HYDRAULIC CHARACTERISTICS OF THE ANAEROBIC CONTACT PROCESS FOR SEWAGE TREATMENT

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Robert A. Taft Sanitary Engineering Center
Public Health Service
U. S. Department of Health, Education, and Welfare
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The work to be described is aimed at developing suitable means of sewage treatment for the relatively small peripheral community ranging down to the ten-house subdivision.

Consideration of effluent objectives and desirable plant operational requirements is needed to put this discussion in perspective. Where it works well, the septic tank-tile field system handles the effluent suitably by putting it in the ground. With surface disposal of effluents there are at least four factors deserving consideration:

(1) Infectious materials in effluents are especially serious in residential areas where children play.

(2) Ponded fertile waste water can support the growth of hordes of mosquitoes.

(3) Odor nuisance and unsightly material are unacceptable in residential areas.

(4) Costs must be compatible with the ability of the community served to pay for the service.

The discharge of sewage effluents to the ground in suburban areas where children play deserves very careful consideration. The citizen sometimes has a poor understanding of possible infection of his children as they play in the polluted water in the ditch. This does not, however, relieve the sanitary engineer and public health and regional planning authorities, or the builder, of responsibility for preventing this very obvious menace to community health.

The control of the level of infectious material in sewage discharges is a problem that has never been given complete consideration. Public health thinking currently accepts the idea that settled sewage may be discharged to the Ohio River or the Mississippi River. In the case of smaller water courses, stream oxygen level is frequently the governing criterion. As we leave the larger waterways and get closer to the open storm sewer, we lose accepted definition of what is desirable, what is tolerable, and what is dangerous. After a preliminary consideration, the authors have tentatively decided that it is desirable to treat neighborhood sewage to the degree that it is less of a potential health hazard than ordinary suburban storm water in sewered areas, but not necessarily of the same bacteriological quality as bathing water.

Regardless of how well sewage may be treated, effluents can be a very fine environment for the growth of the larvae of culex mosquitoes. Where ponded waste waters are supporting the larvae of mosquitoes, the citizen has rarely put cause and effect together. The relationship must be recognized, however, and effluents standing in stagnant puddles in flat grassy ditches cannot well be tolerated.

The effluent characteristics which strike the public most forcefully are the odor and the appearance. Further, a housing developer cannot afford to consider an installation which will impair the marketability of the property he is developing. It must be accepted, therefore, that any practical plant will totally avoid odor nuisance and unsightly appearance.

Both the initial and the operating costs of the installation must be such that the householder can afford them. Cost covers many factors. The land required for the plant is important, and of equal or greater importance is possible impairment of the utility of land adjacent to the plant for housing use. The ten-house subdivision simply cannot afford to write off ten acres of land adjacent to its sewage disposal facility as a buffer strip to separate the householder from odor nuisance. Operating costs must be held down by deliberately designing the plant to operate with little maintenance and attention. A further long-range cost factor is the suitability of the plant for eventual integration into a sanitary district or the sewage disposal scheme of a larger community. This is a factor which at least requires a central collection system, suitably located with respect to a potential interceptor.

In this paper we cannot pretend to have approached a solution to the total problems considered above. Our scope is limited to presenting work done to develop essential components of a small, simple sewage treatment process as a step toward reasonable ultimate goals.

Plant Design and Detention Characteristics:

Earlier papers[1, 2] have described the elements of the approach being explored. Briefly, prior evidence has shown that long detention up-flow treatment in an anaerobic tank containing an anaerobically stabilized sludge followed by further anaerobic contact in an up-flow chamber packed with rock yields very efficient solids removal. In laboratory bench studies efficiency of B.O.D. removal, measured

directly, or estimated from C.O.D. figures ran at levels generally in excess of 65% even at temperatures of 4°C. Pilot plant studies have yielded good solids removal figures, but in early observations lower efficiency of B.O.D. removal was obtained. After a number of changes, recent B.O.D. removals have tended to approach those obtained in the laboratory at comparable temperatures.

The pilot plant referred to is located at the sewage disposal plant at Loveland, Ohio. It was put above ground to permit ease of installation, observation, and sampling, and subsequent ease of removal of the plant. Another important factor in putting the plant above ground was a deliberate effort to secure the maximum thermal disturbance of flow which could be anticipated, so that this disturbance could be observed, measured, and evaluated. The plant was given a conical shape to avoid "dead" areas at the bottom which would not be continuously leached by the flow, and so that accumulated or introduced sludge might serve to distribute the flow through the tank. It was also thought that the varying cross-section given by the conical shape might facilitate studies of the settling rate of sludge in the tank. One important factor of difference between the laboratory and the pilot plant installation is the height of the tanks and the thermal gradients present.

The location of the tank above ground accentuates the effects of weather on the system. In the summer, sewage is warmed in passing through the plant, while in the winter the sewage is cooled. In spring and fall either effect may occur depending upon the difference between ambient and sewage temperatures.

The effect of change in temperature of the sewage in passing through the system is best illustrated and explained using photographs of bench observation of the behavior of a dye slug passing through an up-flow conical system shown in Figure 3. The flow rate was adjusted to give the same 18-hour detention time used in performance studies in the pilot plant. The illustrations are photographs of fluorescein dye illuminated by ultraviolet lamps, and taken with an orange filter over the camera lens. Figures 3 and 4 show a time series of flow patterns after introduction of identical slugs of dye at different thermal gradients. In one case, the feed water was substantially cooler than the water in the tank. With density differences to aid, orderly upward displacement of liquid was secured. Without the favorable temperature gradient, or with the temperature gradient favoring short circuiting increasingly less favorable displacement patterns are shown.

As initially designed, the inlet to the first tank of the pilot plant consisted of a 1" pipe at the very bottom of the cone. Later it was decided that the velocity and upward direction of the incoming flow might be having an unfavorable effect on detention and a 2" pipe which fed the sewage downward at a lower velocity was substituted with little beneficial effect on tank retention characteristics. However, the change did result in elimination of any air sucked in through pump packing leaks and pumped into the tank with the sewage, so that this disturbance was avoided. Entrained air is believed to have leaked out through the fittings inside the tank to give a modest air supply on top of the tank, some of which may have escaped after being metered as "gas."

The behavior of digested sludge as a distributor for the incoming flow was also studied in the laboratory models. Photos were not practical to illustrate behavior, but the sludge had little beneficial effect in producing an evenly distributed flow. The flowing liquid simply formed channels in the sludge.

The detention of slugs of tracers in the pilot plant tanks has been studied a number of times. Figure 5 shows integral detention curves characteristic of the spread in detention patterns observed in the primary treatment tank. With favorable temperature, i.e. ambient temperature much higher than sewage temperature, a detention pattern such as is shown by curve (3) in Figure 5 was secured. At the other extreme, a cold weather curve (with ambient temperature well below that of the sewage) is shown by curve (1). Other conditions tend to yield intermediate detention pattern such as is shown by curve (2).

Some values picked off Figure 5 give a striking picture of the effect of weather on tank detention, and particularly the fraction of the flow passing through the tank with little detention therein.

Table I

Per Cent of Tracer Slugs Passing Through the Primary Tank with Different Ambient Temperatures

Time (Hours)	% Theoretical Detention Time	Ambient Temperature 1°C	15°C	30°C
2	11	10	4	0
4	22	25	15	3
6	33	33	28	13
10	55	52	49	44
13	72	64	64	64

In these detention studies both a chemical tracer (fluorescein dye) and a radioactive tracer (Rubidium 86) were used with no significant difference in the patterns shown by the two procedures. In the differential detention curves on the over-all process and on the primary tank shown in Figure 6, both types of tracers were used simultaneously. Here also both approaches yield the same picture of tank performance.

Biological Populations:

In the earlier bench scale laboratory studies[1], gas escape ports were provided for both the primary sludge tank and the secondary rock contact chamber. In the absence of sustained gas production these gas vents also provided a means for admission of small amounts of air. Microscopic examination of sludges revealed biological populations which contained a number of organisms generally considered to be obligate aerobes. In these studies sulfides were generally low or absent in the final effluent.

On several occasions in the pilot plant a mat of material, largely fungal mycelia, including huge numbers of organisms classified as obligate aerobes, was found floating on top of the primary tank. This occurred during periods when sulfides in primary effluent were at a low level. Other factors changed concurrently, particularly sludge accumulation and temperature, and during the same period sulfides were formed in the secondary tank which was continously open to the atmosphere at the discharge surface. The connection between the biological surface mat and sulfide levels may be entirely

happenstance, but control of sulfide is so important that all observations having possible bearing on the situation are considered worth reporting.

Chemical Problems and Performance Characteristics:

Observations of tank performance has presented a number of difficulties. The feed to the plant, while constant in flow rate so far, has undergone all the variations of quality and strength normally encountered in domestic sewage. The earliest pilot plant observations were simply based on hourly grab samples taken during the normal 8-hour work day. Next, samples of influent and effluent were taken over several 24-hour periods, and an 8-hour sampling period was selected to correspond in its average strength to the average over the day. This was still unsatisfactory, and was supplanted by automatic sampling with solenoid valves which open at 1/2-hour intervals to send sample portions into compositing vessels.

Effluent sampling has been less critical than influent sampling. The detention characteristics of the primary tank, coupled with the effect of sludge accumulated in the system, have led to effluents (both primary and secondary) which, with the exception of sulfides, show slow variation in composition.

The plant presents a number of difficulties for the investigator bent on making a material balance. Methane loss in solution is a readily available mechanism for undetected escape of innocuous B.O.D. At 0°C, in contact with a combined methane and water vapor pressure of 1 atmosphere, the solubility of methane in water is 40 p.p.m., while at 20°C under otherwise similar conditions the solubility of

methane is 23 p.p.m.[3]. Forty p.p.m. of methane represent an ultimate B.O.D. of 160 p.p.m. In terms of the procedures used, methane dissolved in water shows no chemical oxygen demand, and usually shows no 5-day B.O.D. although B.O.D. is found if a longer incubation period is used[4]. Methane representing as much as 100 p.p.m. of 5-day B.O.D. can be present in an effluent and not be noted by any of the usual procedures.

The plant studied favors the development of ammonium carbonate in the treated sewage. This material can go totally unnoted as solids or material carried out in the effluent, simply because it leaves no residue upon evaporation.

Even the fate of mineral components in the food is difficult to assess and the amount of measurement required to make such assessment has not been attempted. Salts of ammonia (about 30 p.p.m. of NH_3/N are present in effluents) favor solution of some components of the mineral matter, such as calcium or magnesium. Ferric iron can be reduced to ferrous iron and carried out in solution. Sulfates are in variable degree reduced to sulfides and in some parts of the system reoxidized to sulfur. Interpretation of simple sanitary parameters in the usual way is not possible.

A running record of some important effluent characteristics is shown in Figure 7. Beginning at about the 25th week of operation (in January, 1957) is what may prove to be a definite break in the treatment efficiency. This coincides with the coldest weather of the year, the poorest detention in the tank, and no substantial change in the solids content of either primary or secondary effluent. A records check shows two changes coincident with this period: (1) For a

period of 2 weeks, starting with the 25th week, the flow rate was approximately doubled, and (2) at the start of the 27th week the piping changes previously noted were made.

It is difficult to consider doubling the volumetric load, or a piping change which did not substantially improve detention, as responsible for the apparent performance improvement. Increased sludge accumulation is a possible factor, but the build-up of sludge would be expected to occur fairly regularly. Also, after introduction of about 160 pounds of digested sludge during the tenth week, effluent quality showed no evidence of improvement. During the period after the improvement in effluent quality, gas meter readings indicated about 225 ft.^{3} of gas as having passed through the meter. Analysis of gas samples from the space above the primary tank, and analysis of primary effluent for methane indicated that little or no methane was produced during the period. Apparently the meter readings were largely a measure of air pumped into the system.

This postulated air leak could be related to the syncline mat noted previously, and it may also be tied into the indicated improvement in effluent quality. Air is now being trapped out of the tank and further examination of the value of air in contact with the water surface of the primary tank is planned.

The primary tank contained about 300 lbs. of solids on March 18. We are looking forward with a great deal of interest to the spring warm-up to see whether we will get a disturbance such as would be anticipated with an Imhoff tank. In previous laboratory

work[1, 2] a bench-scale model was moved across a warm-up period with only minor disturbance, giving some basis for expecting an orderly temperature transition.

The Present Status of the Work

In relation to proposed usage, sulfide levels and odor characteristics of effluent are extremely critical. A plant can have very fine efficiency of treatment and still be a total failure if odors from the plant or its discharge give too much "local color" to the surrounding area. In this frame of reference, the secondary tank requires re-examination and consideration of alternative processes in view of the continued generation of sulfides therein. So far, the primary tank has yielded effluents of relatively high pH and modest sulfide content and the odors of its effluents have been very tolerable. However, we still have to operate the plant during a summer period. Laboratory experience has led us to hope that sulfides in objectionable quantity will not develop, but a constant awareness of this possibility has been maintained, and as a result this paper has presented a great deal of thready observation with regard to factors having a possible bearing on sulfide containment.

As was previously noted, the feed rate was doubled and detention time cut in half for a two-week period, starting during the 25th week of operation, with a subsequent trend toward improved effluent quality. However, we still have to operate the plant with the highly fluctuating short-time flow characteristics, or the daily loading patterns which would be encountered in practice. Important

criteria of plant design, still to be approached experimentally, include the establishment of minimum workable detention time and maximum tolerable rise rates in the tank, both as averages and over short periods of heavy load.

The spring warm-up is at hand, and in a very short time, the plant should reveal whether there will be an acute disturbance with the warm-up of the sludge accumulated in the tank. Even if such disturbance occurs, it cannot be considered to be a serious flaw in performance for application of the process in the small suburban community because it would be simple to schedule sludge pumping to control such difficulty. A violentperiod of upset would, however, alter perspectives in regard to larger installations.

Putting the tanks below ground is clearly indicated unless head is required for further processing. Experimental work to date has shown no clear-cut advantage to justify the extra cost of the conical tank. However, the question of whether the conical shape is advantageous in retaining solids has yet to be examined.

SUMMARY:

Performance characteristics required in a plant to treat sewage from a few houses so that it will be suitable for discharge to open storm sewers have been discussed. The possibility of using anaerobic treatment in simple units is being explored. Some of the hydraulic problems of design, and chemical problems relating to observation of system performance have been presented. The up-flow sludge contact system described shows promise of becoming a useful addition to sewage disposal procedures, particularly for the very small installation.

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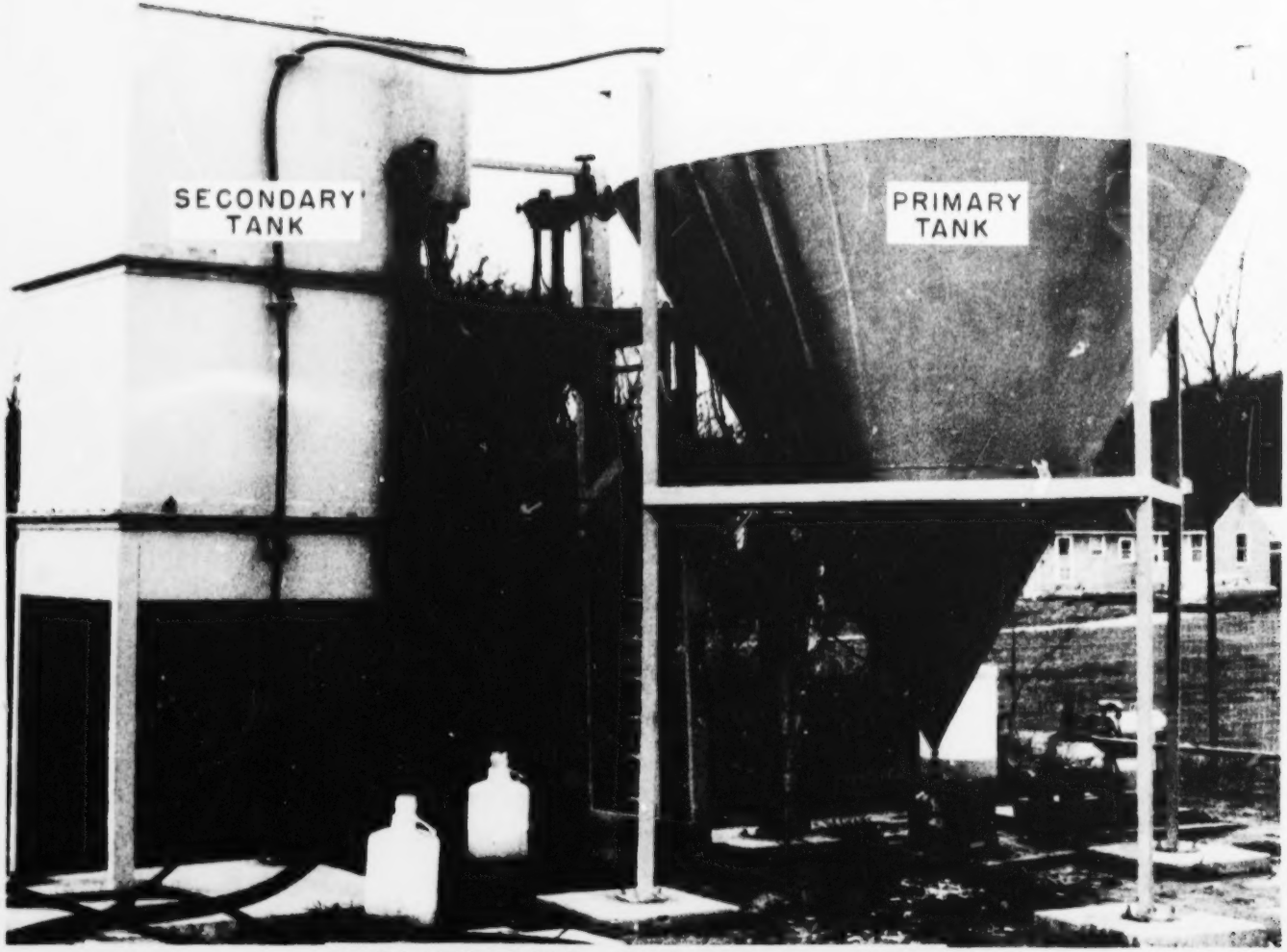

LOVELAND PILOT PLANT

FIGURE 1

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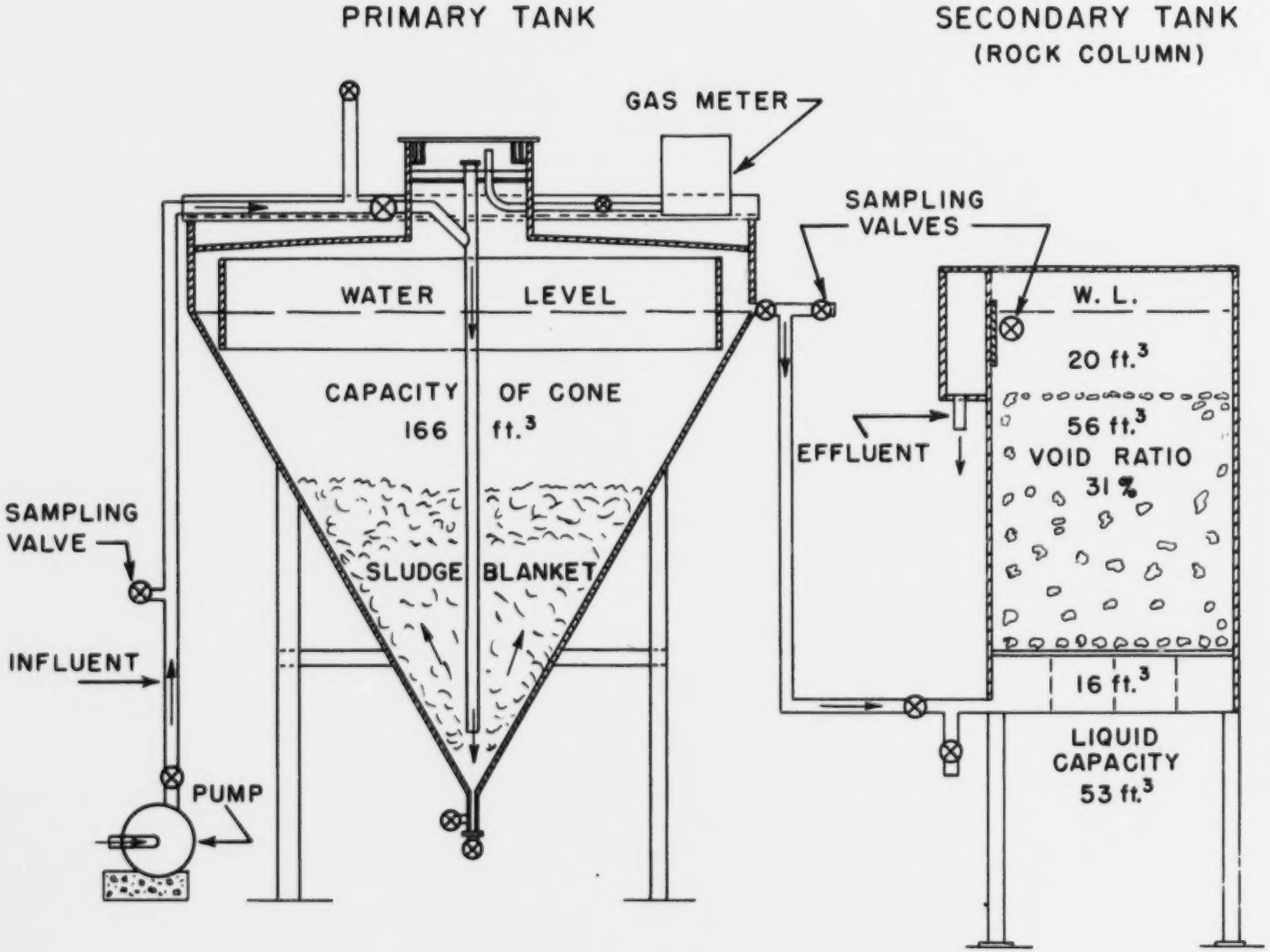
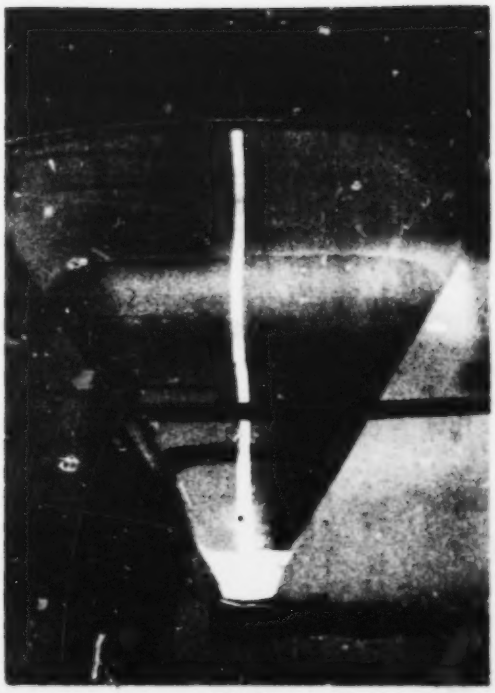


CROSS SECTION OF PILOT PLANT

FIGURE 2



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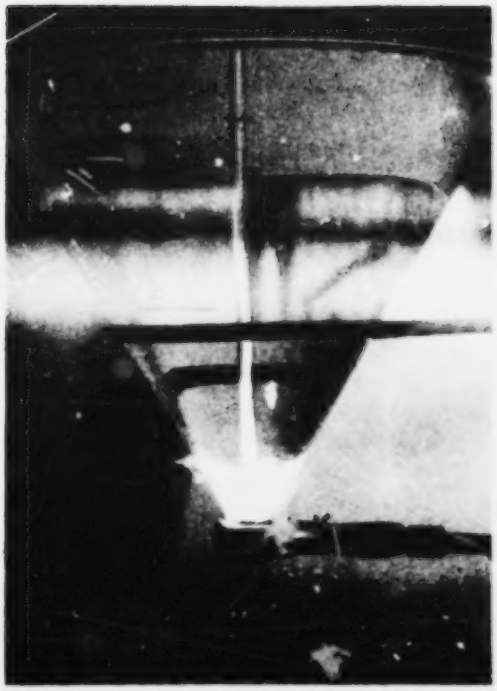

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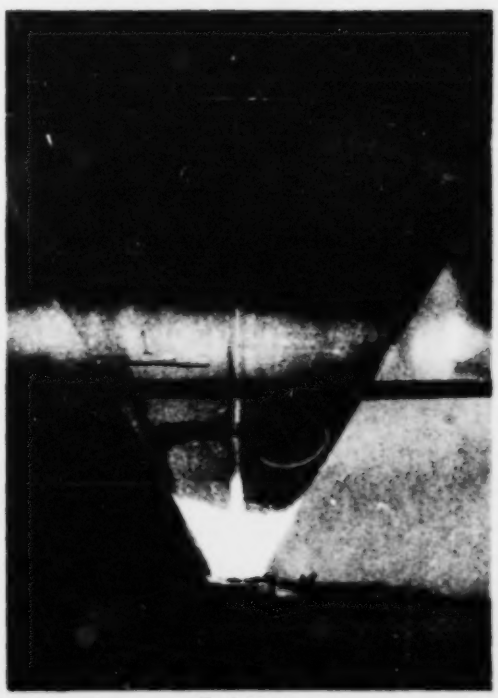

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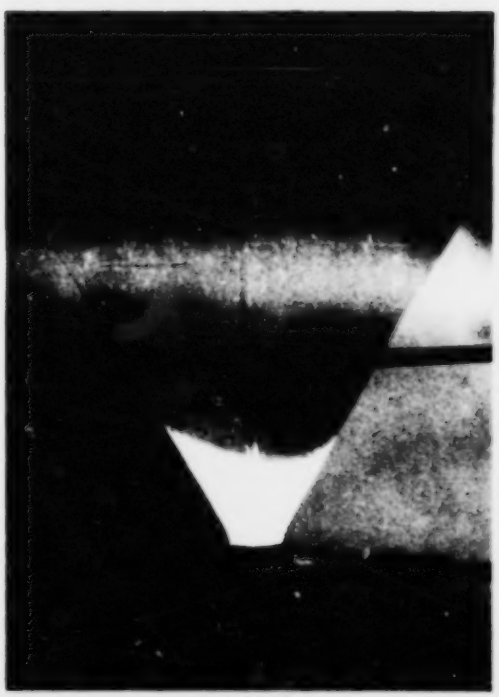

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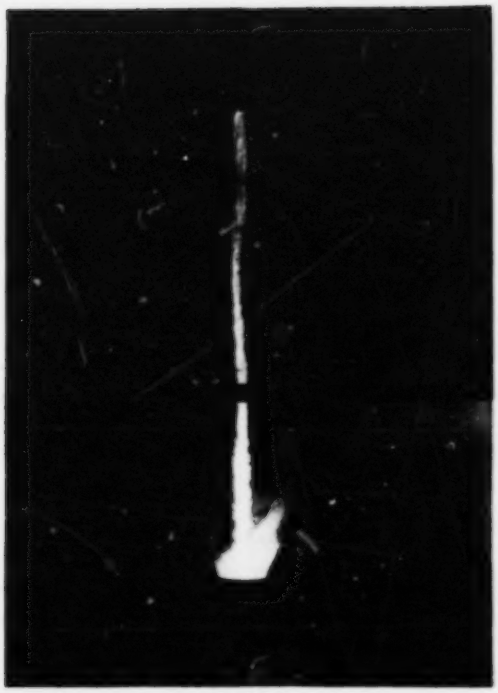
AFTER INTRODUCTION OF TRACER

THERMAL EFFECTS ON FLOW PATTERNS

INCOMING LIQUID 10°C COOLER THAN TANK LIQUID

FIGURE 3



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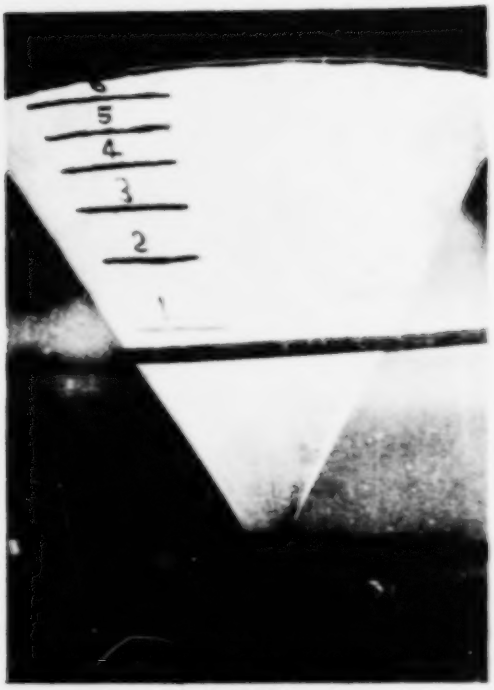

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AFTER INTRODUCTION OF TRACER

THERMAL EFFECTS ON FLOW PATTERNS

INCOMING LIQUID 10°C WARMER THAN TANK LIQUID

FIGURE 4

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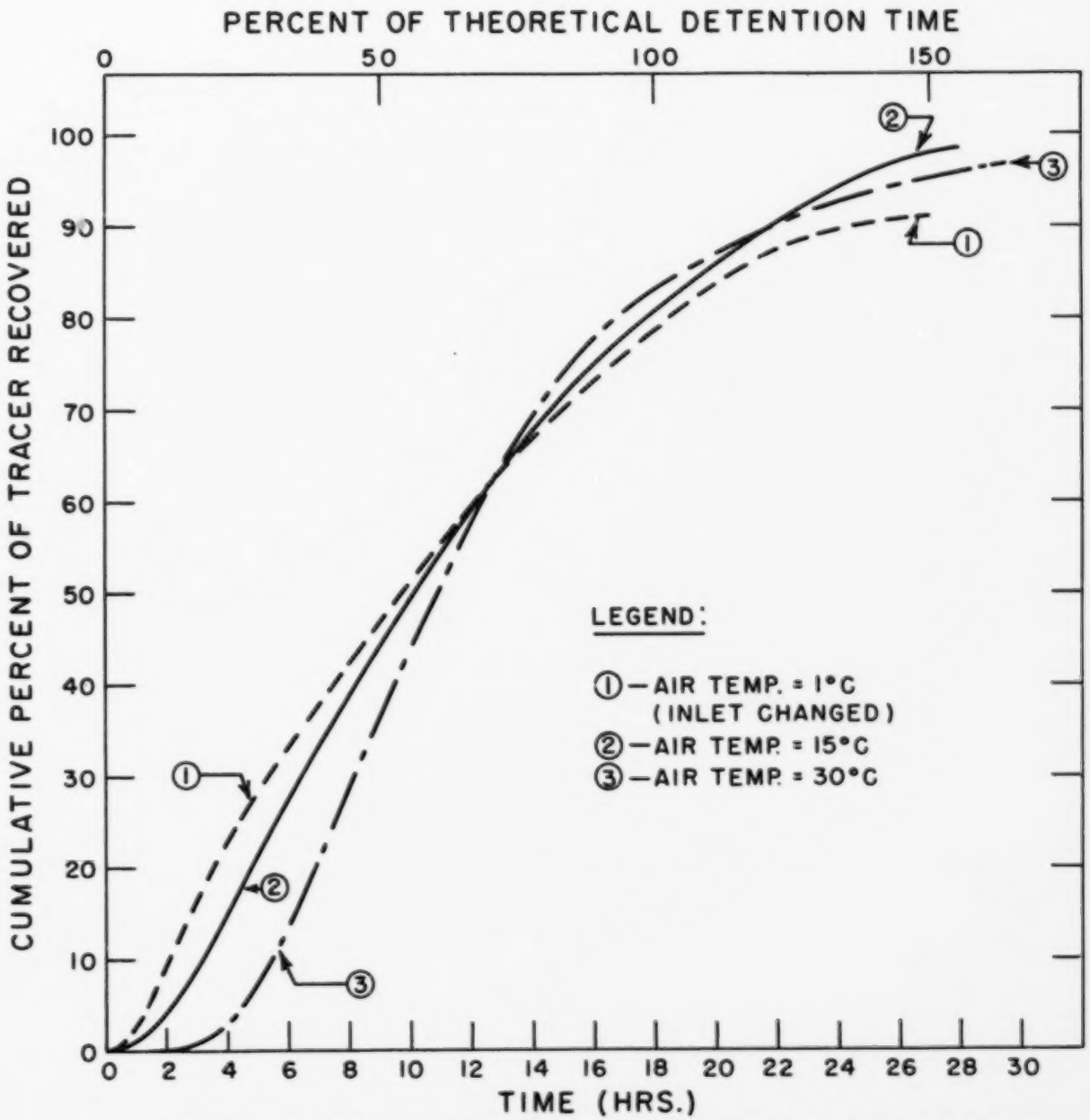
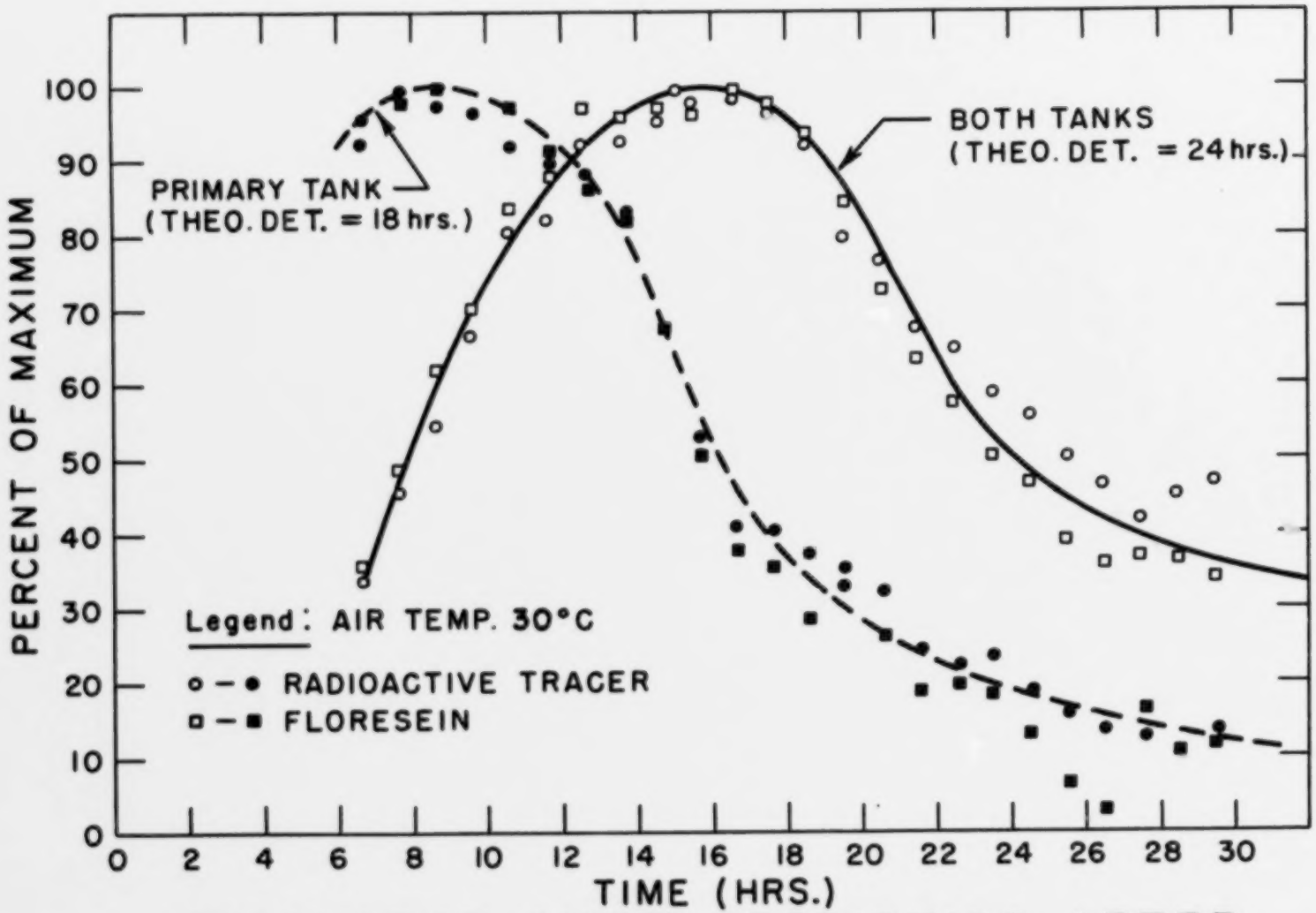


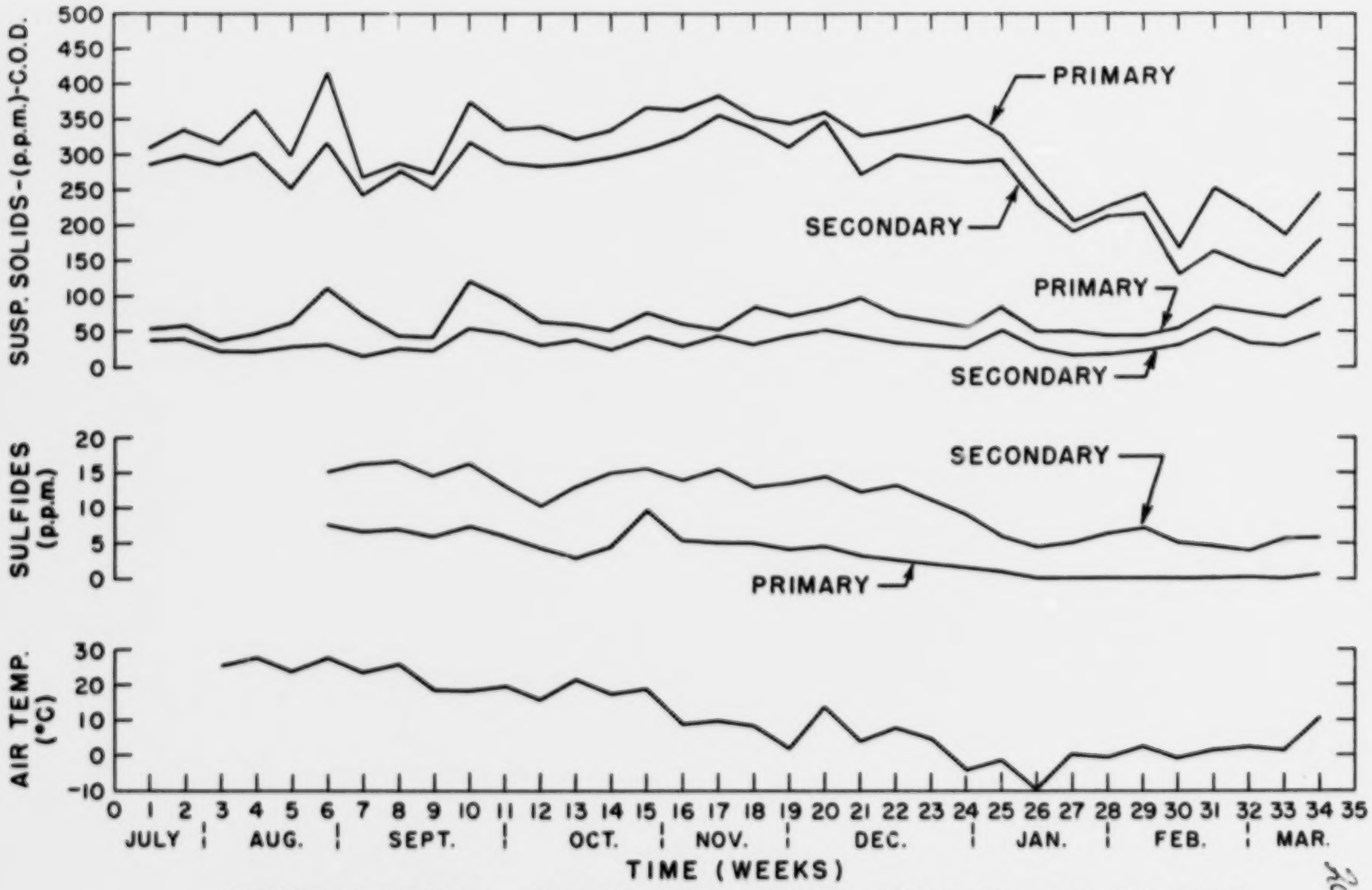
CUMULATIVE RECOVERY FROM PRIMARY TANK OF INSTANTANEOUS TRACER DOSAGE

FIGURE 5



DISCHARGE CHARACTERISTICS AFTER INSTANTANEOUS TRACER DOSAGE

FIGURE 6



OPERATIONAL DATA OF LOVELAND PILOT PLANT

FIGURE 7